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BENEFICIATION OF TWO SAMPLES OF WOLLASTONITE FROM MARMORA, ONTARIO

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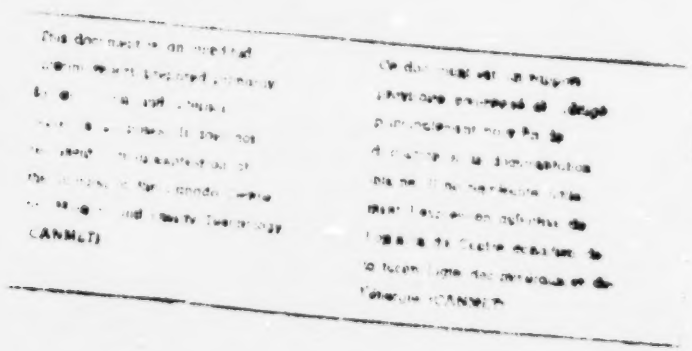

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BENEFICIATION OF TWO SAMPLES OF WOLLASTONITE FROM MARMORA, ONTARIO

by

P.R.A. Andrews*

ABSTRACT

Two samples of calcitic wollastonite analysing approximately 25% wollastonite and 70% calcite were beneficiated to produce separate calcite and wollastonite concentrates. One sample, which contained diopside was characterized by a greenish colour; the other, though white in appearance contained trace amounts of pyrite. Processing included wet and dry magnetic separation to remove diopside and other iron-oxide containing minerals. Flotation to produce separate calcite and wollastonite concentrates was attempted by two methods. Anionic sodium oleate flotation of calcite at pH 7 using between 205 and 310 g/t of collector successfully concentrated calcite to 93.7-97.5% $CaCO_3$. Concentration of wollastonite in the rougher tails was to 86-93% with 0.57-0.62% Fe_2O_3. Cationic flotation using between 75 and 100 g/t Arquad T 50 (trimethyl tallow ammonium chloride), a tertiary amine, at pH 9 successfully concentrated wollastonite to 86-89% $CaSiO_3$ with 0.33-0.82% Fe_2O_3. Further processing employing gangue depressants and reverse flotation of remaining silicates should further concentrate calcite and wollastonite.

Keywords: Calcite, wollastonite, magnetic separation, anionic and cationic flotation

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ENRICHISSEMENT DE DEUX ECHANTILLONS DE WOLLASTONITE DE MARMORA, ONTARIO

par

P.R.A. Andrews*

RESUME

Deux échantillons de wollastonite calcitique titrant environ 25 % de wollastonite et 70 % de calcite ont été enrichis en concentrés séparés de calcite et de wollastonite. Un échantillon contenant de la diopside était caractérisé par une couleur verdâtre: l'autre, quoique blanc en apparence, contenait des traces de pyrite Le traitement a consisté en une séparation magnétique en milieux sec et humide visant à éliminer la diopside et d'autres minéraux contenant des oxydes de fer. On a essayé deux méthodes de flottation pour produire des concentrés séparés de calcite et de wollastonite. La flottation anionique à l'oléate de sodium de la calcite, à ph 7, avec des teneurs en collecteur de 205 à 310 g/t a permis de réaliser un concentré de calcite contenant entre 93,7 et 97,5 % de $CaCO_3$. La wollastonite dans les produits de queue des cellules dégrossisseuses avait une concentration de 86 à 93 % avec de 0,57 à 0,62 % de Fe_2O_3. La flottation cationique à raison de 75 à 100 g/t d'Arquad T 50 (chlorure de triméthylammonium suifeux), une amine tertiaire, à pH 9, a permis de concentrer la wollastonite à 86-89 % de $CaSiO_3$ avec de 0,33 à 0,83 % de Fe_2O_3. Un traitement additionnel avec des déprimants de gangue et une flottation inverse des silicates résiduels devraient permettre de concentrer davantage la calcite et la wollastonite.

Mots clés: calcite, wollastonite, séparation magnétique, flottation anionique et cationique

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INTRODUCTION

In February 1987 two samples of calcitic wollastonite-bearing marble, each weighing approximately 80 kg, were received from the Ministry of Northern Development and Mines. These samples, white and green in appearance, were collected from two distinct geological zones and are considered to be representative of the deposit. The location of the deposit is 5 km east of Marmora, Ontario. Each variety of wollastonite is referred to by the colour phase, but to avoid unnecessary repetition each variety is also referred to by the colour letter.

e.g., Green-phase wollastonite - Sample G
White-phase wollastonite - Sample W.

SAMPLE DESCRIPTION

White-Phase Wollastonite

Sample W is a white-grey fine-grained calcitic marble containing fine-grained subhedral nematoblastic crystals of white wollastonite. Trace amounts of sulphides, principally pyrite, are disseminated throughout the skarn.

Green-Phase Wollastonite

Sample G is a light green fine-grained calcitic wollastonite bearing marble containing fine-grained subhedral nematoblastic crystals of white wollastonite. Minor associated mineralization includes trace amounts of sulphides, principally pyrite, disseminated throughout the sample with preferred association within calcitic grains.

The presence of approximately 2% diopside as finely dispersed encapsulated grains, 100 to 200 μm in size, in the aggregate crystals of wollastonite imparts the greenish appearance. The green zone also is more highly crystallized, which is apparent when data obtained from X-ray diffraction of the white and green-phase varieties are compared. A more pronounced peak with the green-phase variety indicates a higher degree of crystallization.

SIZE REDUCTION

Both Sample G and W were stage-crushed using a combination of large and small jaw crushers to approximately 6 mm. Further comminution was conducted on a 20 kg riffled portion of each sample; the remaining portion of each was stored. After reduction to 2.4 mm using a laboratory roll crusher a head sample was prepared from Sample G and W crushed material.

HEAD SAMPLE

White-Phase Wollastonite

A representative 200 g portion for size analysis was wet and dry screened and results are reported in Table 1. Each size fraction was examined by optical microscopy to determine mineral association and wollastonite liberation size; results are reported in Table 2. The approximate mineral composition was calcite 70% and wollastonite 25-30% with trace amounts of pyrite and iron oxide minerals.

Green-Phase Wollastonite

A representative 200 g portion for size analysis was wet and dry screened and results are reported in Table 1. Each size fraction was examined by optical microscopy to determine mineral association and wollastonite liberation size; results are reported in Table 3. The approximate mineral composition was calcite 70%, wollastonite 25%, the remaining 5% accounting for diopside, other silicate minerals, trace amounts of pyrite and iron oxide minerals.

PROCESSING

Secondary Crushing

The results of optical microscopy on each phase variety of wollastonite indicated that the liberation size was 420 μm, so that each 20 kg portion was stage-crushed to 420 μm using a laboratory roll crusher. After crushing, each sample was dry screened at 150 μm.

Magnetic Separation

Wet and dry magnetic separation to remove diopside, etc., was conducted on Sample G and W sized products (-420 +150 μm and -150 μm). Dry magnetic separation was conducted on -420 +150 μm material using a perm-roll separator, and wet magnetic separation on -150 μm material using a Jones high intensity separator; results are reported in Table 4.

Flotation

Wollastonite was concentrated by two techniques: flotation of calcite from wollastonite and other silicates, and flotation of wollastonite from calcite and other silicates. The former method employed sodium oleate as a collector for calcite, and the latter method the quarternary amine collector Arquad T 50 (trimethyl tallow ammonium chloride) as collector for wollastonite.

Preliminary testwork to establish optimum parameter conditions was conducted with the -420 +150 μm fraction of Sample G using the calcite flotation technique. Flotation was initially conducted on unground -420 +150 μm material; results are reported in Table 5. The influence of variable grind size on flotation performance at constant pH and collector concentration is summarized by the results in Table 6. The results of the combined effect of variable grind size and collector concentration at constant pH are presented in Table 7. Two further series of tests were conducted using the wollastonite flotation method. The results in Table 8 demonstrate the influence of variable collector concentration on wollastonite flotation performance at constant pH and grind size, and the results in Table 9 investigated the influence of variable grind size at constant pH and collector concentration.

The -150 μm portion of Sample G was treated separately and the results of testwork using the calcite flotation technique are reported in Tables 10 to 12. The results in Table 10 indicate the influence of variable collector concentration at constant pH and grind size. The results in Table 11 indicate the influence of variable pH at constant collector concentration and grind size. The results in Table 12 indicate the effect of variable grind size at constant pH and collector concentration. Two series of tests were conducted using the Arquad T 50 method. The results in

Table 13 indicate the influence of variable collector concentration at constant pH and grind size. The results in Table 14 indicate the influence of variable grind size at constant pH and collector concentration.

Remaining testwork was conducted with Sample W. The influence of variable collector concentration at constant pH and grind size using -420 +150 μm material was investigated by the calcite flotation method with results reported in Table 15, and by the wollastonite flotation method with results reported in Table 16. The influence of variable grind size at constant pH and collector concentration also was investigated by each flotation method. Results obtained with the sodium oleate method are reported in Table 17 and with the Arquad T 50 method in Table 18.

The -150 μm portion of Sample W was treated separately. The effect of variable collector concentration at constant pH and grind size was investigated using each collector system. The results obtained with sodium oleate are reported in Table 19, and the results with Arquad T 50 in Table 20. The influence of variable grind size at constant pH and collector concentration was also investigated for each collector system. The results obtained with sodium oleate are reported in Table 21, and the results obtained with Arquad T 50, in Table 22. Flotation parameter and reagent concentration data for each sample at each size fraction are presented in Tables 23 to 26.

RESULTS

Evaluation of testwork results was based on analytical data, specifically Fe_2O_3, LOI and acid soluble. The acid soluble analysis was interpreted as per cent calcite, since calcite was the only carbonate mineral detected. The acid soluble analyses for products high in wollastonite were omitted because of suspected interference from decomposed wollastonite giving erroneously high acid soluble analyses. The acid soluble technique involved heating products with concentrated HCl prior to dilution, and it is known that wollastonite gelatinises in concentrated HCl.

The grade of wollastonite was inferred from the LOI analysis. Selected high-grade wollastonite concentrates were subjected to a staining technique using alizarin red dye which preferentially stains calcite pink

leaving wollastonite unstained. The estimated calcite content of wollastonite concentrates approximately equalled the LOI analysis as indicated by the following results.

Product	% Wollastonite	% Calcite	% LOI
Test 10 final concentrate	85 to 90	10 to 15	4.44
Test 12 final concentrate	80 to 85	15 to 20	8.33

Magnetic Separation

The iron oxide rejection for Sample G was approximately 50% in the -420 +150 μm fraction, and correspondingly higher at approximately 80% in the -150 μm fraction. When considering Sample W, the iron oxide rejection was less efficient; for the -420 +150 μm fraction only 3.1% was rejected and for the -150 μm fraction only 21.4% was rejected. These results are consistent with the more efficient removal of diopside from Sample G than the removal of non-magnetic pyrite from Sample W.

Flotation

Sample G: -420 +150 μm

The results of Tests 1 to 3 in Table 5 demonstrate that high-grade calcite, >94% $CaCO_3$ can be obtained on unground material at pH 7.0 using between 305 and 410 g/t sodium oleate. Wollastonite was concentrated in the rougher tailings up to approximately 85% in Tests 1 and 2.

The influence of increasing fineness of grind on flotation performance was demonstrated by the results in Table 6. By increasing the -75 μm portion from 13.5% to 43.5% by weight, and maintaining the pH at 7.0 and sodium oleate concentration at 310 g/t, the grade of calcite concentrate was increased from 94.52% $CaCO_3$ in Test 4 to 97.51% $CaCO_3$ in Test 7. Brightness values increased correspondingly from 67.2% in Test 4 to 77.9% in Test 7. Wollastonite grade was similarly increased, by increasing the fineness of grind, from approximately 85% in Test 4 to 93% in Test 7 as indicated by the LOI analyses. Brightness values were similarly increased from 62.7% in Test 4 to 68.5% in Test 7. Weight recovery of both calcite at approximately

65% and wollastonite at approximately 26% appears to be independent of fineness of grind.

The results in Table 7 demonstrate the influence of increasing collector concentration at two different levels of fineness of grind. By maintaining a grind of 19.0% -75 μm by weight, pH constant at 7.0, and increasing the sodium oleate concentration from 310 to 420 g/t, there was a slight increase in calcite concentrate grade from 92.3% $CaCO_3$ in Test 5 to 93.6% $CaCO_3$ in Test 8. The wollastonite grade in the rougher tails was increased from approximately 85% in Test 5 to 89% in Test 8 as indicated by LOI analyses. At a finer grind of 43.5% -75 μm by weight and repeating the same test conditions, a decrease in calcite grade from 97.5% $CaCO_3$ for Test 7 to 95.0% $CaCO_3$ for Test 9 was noted. The wollastonite grade in the rougher tails of Tests 7 and 9 remained virtually unchanged. By increasing the collector concentration, at each grind size, there was a slight increase in weight recovery of calcite and a slight decrease in weight recovery of wollastonite.

Preliminary testwork with the quarternary amine collector Arquad T 50 indicated that wollastonite could be floated from calcite. The results in Table 8 demonstrate the influence of increasing collector concentration from 50 g/t to 100 g/t at pH 9.0 and a grind of 13.5% -75 μm. The best grade of wollastonite concentrate at approximately 88% was obtained in Test 10 which employed the least amount of collector. In Test 12 calcite concentration to >93% $CaCO_3$ was obtained in the rougher tails. Weight recovery of wollastonite increased and weight recovery of calcite decreased with increasing collector concentration. The results in Table 9 demonstrate the effect of increasing grind size from 13.5% -75 μm to 43.5% -75 μm on wollastonite grade, at pH 9.0 with 75 g/t of collector. Wollastonite grade increased from approximately 83% in Test 11 to approximately 87% in Test 15. Increased grind size had very little effect on calcite grade but calcite (LOI) recovery increased from 87.1% in Test 11 to 92.7% in Test 15. Increasing the fineness of grind also significantly increased the brightness of both wollastonite and calcite concentrates.

Sample G: -150 μm

Two series of tests were conducted using sodium oleate collector: variable collector concentration at constant pH and grind size, and variable pH at constant collector concentration and grind size. The results in Table 10 indicate that by increasing collector concentration calcite concentrate grade is slightly decreased, although weight recovery remains independent of increasing collector concentration between 310 and 420 g/t. Wollastonite concentration appears best at 365 g/t (Test 17) where approximately 93% wollastonite was obtained at a weight recovery of 31%. Brightness values for both calcite and wollastonite concentrates regardless of test conditions were approximately equal at 73%.

The influence of variable pH (Table 11) on flotation of calcite, between pH 7 and 9 at a sodium oleate concentration of 310 g/t results in a slight decrease in calcite grade with increasing pH. Weight recovery remained unchanged with increasing pH. Wollastonite recovery is more influenced by an increase in pH such that the weight recovery decreases from 33.4% at pH 7 (Test 16) to 23.5% at pH 9 (Test 20). Conversely the grade increased from approximately 92% in Test 16 to approximately 94% for Test 20. Brightness values for each mineral were approximately equal at 73%, although there was a very slight increase in brightness for both calcite and wollastonite concentrates with increasing pH. The effect of increasing grind size (Table 12) indicates a negative effect on wollastonite grade and calcite recovery. Calcite grade and brightness values were, however, significantly increased from 96.4% $CaCO_3$ and brightness 73% in Test 16 to 99.0% $CaCO_3$ and brightness 86.2% in Test 22.

When using Arquad T 50, the results in Table 13 show the effect of increasing collector concentration while maintaining pH and grind size constant. Weight recovery of wollastonite increased from 27.9% for 75 g/t of collector (Test 23) to 38.3% for 130 g/t of collector (Test 25); there was a corresponding decrease in grade from approximately 90% to 86%. Conversely calcite weight recovery in the rougher tails decreased from 65.1% in Test 23 to 52.9% in Test 25. At the same time calcite grade increased from 84.4% $CaCO_3$ in Test 23 to 96.4% $CaCO_3$ in Test 25. Brightness values for both calcite and wollastonite concentrates regardless of test conditions were approximately 70% for wollastonite and 74% for calcite. The influence of

increasing fineness of grind (Table 14) indicated a negative effect on both calcite and wollastonite grade; weight recovery of each was independent of increasing fineness of grind.

Sample W: -420 +150 μm

Four tests were conducted using variable additions of sodium oleate at pH 7 and a grind of 23.4% -75 μm. The results of these tests in Table 15 indicate that the best results for both calcite and wollastonite concentration were obtained with the least quantity of collector, 205 g/t. When using 205 g/t sodium oleate (Test 28), a calcite concentrate with a 64.6% weight recovery and 93.66% $CaCO_3$ grade was obtained. Increasing the quantity of collector above 205 g/t had a detrimental effect on calcite weight recovery and wollastonite grade. The concentration of wollastonite in the rougher tails was approximately 86% when using 205 g/t collector. Brightness values for Test 28 were 83.5% for the calcite concentrate and 72.5% for the wollastonite concentrate.

Testwork was conducted with variable additions of Arquad T 50 collector at a grind of 23.4% -75 μm and a pH of 7.0. In Table 16 the best results for calcite and wollastonite flotation were obtained using 75 g/t of collector (Test 33). The wollastonite concentrate analyzed approximately 86% with a weight recovery of 23%, and the concentration of calcite in the rougher tails was 91.3% $CaCO_3$ for a weight recovery of 67.2%. Brightness values for Test 33 were 83.6% for the calcite concentrate and 70.7% for the wollastonite concentrate.

The effect of increasing fineness of grind on calcite and wollastonite flotation performance, using sodium oleate collector, is shown by the results in Table 17. By increasing the fineness of grind from 23.4% -75 μm in Test 28 to 38.3% -75 μm in Test 36, calcite grade was increased from 93.66% $CaCO_3$ to 97.24% $CaCO_3$. Weight recovery decreased from 64.6% to 49.6%. Wollastonite concentration decreased with increasing fineness of grind from approximately 86% in Test 28 to approximately 78% in Test 36. When using Arquad T 50 collector, the effect of increasing fineness on calcite and wollastonite flotation (Table 18) was not significant for either grade or weight recovery.

Sample W: -150 μm

Testwork conducted with variable concentration levels of sodium oleate at pH 7.0 indicated that 305 g/t of collector (Test 41) gave the best results. The product balance of Test 41 in Table 19 indicated that a calcite concentrate analyzing 95.48% $CaCO_3$ with a weight recovery of 73.2% and brightness value of 76.9% could be obtained. The concentration of wollastonite in the rougher tails was approximately 88% wollastonite with a weight recovery of 23.2% and a brightness value of 71.3%.

When assessing the effect of variable concentration of Arquad T 50 at pH 7.0 on calcite and wollastonite flotation, the results in Table 20 suggest that Test 43 conditions were the best compromise between weight recovery and grade of wollastonite. A grade of approximately 80% wollastonite with a 29.2% weight recovery and a brightness value of 68.9% was obtained. The concentration of calcite in the rougher tails of Test 43 was 97.22% $CaCO_3$, with a weight recovery of 60.4% and a brightness value of 84.2%. Although Test 42 produced the highest grade of wollastonite at approximately 92%, the lowest weight recovery was obtained. Similarly, Test 44 produced the lowest grade but the highest weight recovery.

The effect of increasing fineness of grind on calcite and wollastonite flotation performance using sodium oleate collector is shown by the results in Table 21. The best grade and weight recovery combination for calcite was Test 45, where a concentrate analyzing 98.29% $CaCO_3$ at 64.5% weight recovery and brightness value of 82.6% was obtained. Increasing fineness of grind above 75.9% -75 μm resulted in a detrimental effect on calcite flotation. The best results for wollastonite flotation were obtained at a coarser grind of 64.9% -75 μm, Test 41, where wollastonite grade in the rougher tails was approximately 89% and brightness 71.3%. When using Arquad T 50 collector, wollastonite grade increased from approximately 80% in Test 43 at 64.9% -75 μm to approximately 86% in Test 50 at 90.1% -75 μm (Table 22). Weight recovery decreased from 29.2% in Test 43 to 19.6% in Test 50. Increasing fineness of grind reduced calcite grade from 97.22% $CaCO_3$ in Test 43 to 90.44% $CaCO_3$ in Test 50. Brightness values for wollastonite and calcite concentrates were not significantly altered by increasing fineness of grind.

COMMENTS

Wollastonite as a commercial product for ceramic, metallurgical flux, filler and coating applications should be at least 90% wollastonite with less than 1% LOI and less than 1% Fe_2O_3 (Power, 1980). In general, each variety of wollastonite met the minimum wollastonite grade and iron oxide requirements, although the white variety was slightly below the 90% wollastonite specification; the LOI analysis for each variety, however, was greater than 1%. Further processing including magnetic separation and reverse flotation of the remaining silicate minerals should reduce the LOI and Fe_2O_3 levels and increase the wollastonite grade.

Calcite is used mainly in paper, plastics and paint where the criteria for use is brightness, which should be 85% or more. Chemical analysis reports a minimum of 92.5% $CaCO_3$ for dry ground and 95.9% for wet ground calcite (North, 1983). Calcite produced by the oleate flotation technique generally met chemical grade requirements but brightness was less than 85%. Further processing including magnetic separation and gangue depressant addition in flotation should improve both grade and brightness.

PHYSICO-CHEMICAL CONSIDERATIONS

Surface Charge

Calcite is classified as a salt-type mineral and as such surface dissolution occurs as hydrolysis and complex formation reactions. A number of chemical species are produced, some of which according to Samasundaran and Agar (1967) are potential determining: H_2CO_3, HCO_3^-, CO_3^{2-}, Ca^{2+}, $CaHCO_3^+$, $CaOH^+$ and $Ca(OH)_2(aq.)$. Consequently, when calcite is in equilibrium with an aqueous phase at high pH values HCO_3^- and CO_3^{2-} will exist whereas, at lower pH values Ca^{2+}, $CaHCO_3^+$ and $CaOH^+$ species will occur. The point of zero charge of calcite at 8.2 was obtained by the same investigators, and zeta potential was observed to increase in magnitude on each side of the z.p.c.

Wollastonite, $CaSiO_3$ or calcium metasilicate, is classified as a pyroxene typified by the metasilicate single chain. Very little information is available concerning the electrokinetic behaviour of wollastonite and the

z.p.c. is not reported in the chemical literature. It is reasonable to suppose that wollastonite would be chemically similar to other pyroxene minerals, such as enstatite, diopside and augite; the z.p.c.'s of these minerals being in the range 2.8 to 3.8 (Fuerstenau, D.W. and Fuerstenau, M.C., 1982). Further evidence that the z.p.c. of wollastonite might be in this range is indicated by the very large flotation area between pH 3 to 12 when using the cationic collector dodecylamine, and the absence of flotation when using anionic sodium oleate collector (Manser, 1973). Such response to flotation by a cationic collector could be explained by electrostatic attraction in an area of negative surface charge. The mechanism by which wollastonite acquires a surface charge would be by ionization of surface Ca^{2+} ions and hydrolysis of exposed Si ions. In aqueous media, exposed silicon ions can be considered as forming a surface silicic acid, the dissociation of which results in a negative surface charge.

Adsorption

Data obtained by Klassen and Mokrousov, 1963 indicates that there is no direct correlation between the solubility of calcite and calcium oleate, and the amount of adsorbed oleate on calcite surfaces. Such observations indicates that oleate adsorption is more complex than simple ion-exchange mechanisms. The adsorption of oleate on calcite is suggested to be by electrostatic forces below the z.p.c. where calcite is positively charged, and by the chemical forces above the z.p.c. where calcite is negatively charged (Samasundaran, 1969; Mishra, 1982).

Adsorption data for wollastonite is limited and can only be inferred from experimental observations. Thus, the absence of flotation using sodium oleate collector (Manser, 1973) is anomalous; it would be expected to be self-activating in anionic flotation because of the relatively large portion of calcium ions present. Electrostatic or Coulombic forces are suspected because of the larger pH range over which flotation is obtained using cationic dodecylamine collector.

Calcite-Wollastonite Separation

The selective flotation of calcite from wollastonite using anionic sodium oleate can be explained in terms of surface potentials. At pH 7

oleate ions are adsorbed on positively charged calcite surfaces, rather than negatively charged wollastonite surfaces. It is interesting to note that possible ionized silicic acid from wollastonite does not depress calcite. Mishra (1982) found that at pH 8 sodium metasilicate did not depress calcite whereas electrokinetic data indicated adsorption of silicate species on calcite. This behaviour was attributed to the preferential adsorption of oleate ions at the positively charged calcite surface.

Wollastonite flotation at pH 9 can similarly be explained by surface potentials; cationic flotation of wollastonite with Arquad T 50 occurred in a region of negative surface charge for wollastonite. Calcite is unresponsive to quarternary amines thus, wollastonite can be selectively floated from calcite.

CONCLUSIONS

Calcite and wollastonite were successfully concentrated by each flotation technique: anionic sodium oleate flotation of calcite from wollastonite, and cationic Arquad T 50 flotation of wollastonite from calcite.

The best results with each collector system for each sample at each size fraction tested are summarized as follows:

Sample	Size μm	Collector system	Test No.	Calcite conc % $CaCO_3$	Wollastonite % Woll.	Conc % Fe_2O_3
G	+150	Oleate	7	97.5	93	0.62
G	-150	Oleate	17	95.4	93	0.14
G	+150	Arquad T 50	15	90.3	87	0.60
G	-150	Arquad T 50	26	91.0	89	0.33
W	+150	Oleate	28	93.7	86	0.57
W	-150	Oleate	41	95.5	88	0.51
W	+150	Arquad T 50	37	91.5	87	0.91
W	-150	Arquad T 50	49	94.7	86	0.82

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Table 1. Head sieve analyses

Size fraction μm	White phase % wt	Green phase % wt
+2400	0.1	-
-2400 +1200	6.0	16.4
-1200 +600	27.0	25.4
-600 +300	21.4	18.2
-300 +210	9.6	8.2
-210 +150	7.3	6.2
-150	28.6	25.6
TOTAL	100.0	100.0

Table 2. Optical examination of sized fractions of white-phase wollastonite

Size fraction μm	Description
-2400 +1200	- bladed wollastonite occurs as an assemblage with calcite - no separation or concentration - disseminated sulphides occur in trace amounts and are most commonly associated with the calcite
-1200 +600	- essentially the same as -2400 +1200 μm
-600 +300	- wollastonite occurs as bladed blocky subhedral crystals with encapsulated calcite grains - partial liberation - approximately 25% of the size fraction as wollastonite - low aspect ratio 2:1 to 4:1 - disseminated sulphides (pyrite) occur in trace amounts
-300 +210	- liberation was achieved; encapsulated grains of calcite, however, found in the bladed crystals of wollastonite - low aspect ratio 4:1 - approximately 25% of the size fraction as wollastonite - disseminated sulphides (pyrite) occur in trace amounts
-210 +150	- minor amounts of encapsulated grains of calcite are still present in the wollastonite crystals - blocky aggregates of the wollastonite are for the most part broken down thereby yielding a higher aspect ratio of between 8:1 and 4:1 - disseminated sulphides (pyrite) occur in trace amounts - approximately 30% of the size fraction as wollastonite
-150	- wollastonite crystals are essentially free from the calcite grains - disseminated sulphides (pyrite) occur in trace amounts - approximately 30% of the size fraction as wollastonite - aspect ratio is higher at 8:1

Table 3. Optical examination of sized fractions of green-phase wollastonite

Size fraction μm	Description
-2400 +1200	- bladed wollastonite occurs as an assemblage with calcite - coloured silicates are found throughout the sample encapsulated both in the wollastonite and calcite - disseminated sulphides (pyrite) occur in trace amounts and are most commonly associated with the calcite - encapsulated calcite may be found in the wollastonite crystals
-1200 +600	- essentially the same as -2400 +1200 μm - pyrite occurring in subhedral-euhedral modified octohedran cubes in trace amounts - approximately 15% of the size fraction as wollastonite
-600 +300	- wollastonite is partially liberated from the calcitic matrix however, there are still encapsulated diopside grains in aggregates of wollastonite - sulphide (pyrite) is liberated and found finely dispersed throughout the size fraction in trace amounts - approximately 15 to 20% of the size fraction as wollastonite
-300 +210	- liberation is essentially complete; diopside is approximately 90% liberated from the wollastonite aggregate - wollastonite aspect ratio is low between 4:1 and 2:1 - some encapsulated calcite still remains associated with the wollastonite - approximately 20 to 25% of the size fraction as wollastonite
-210 +150	- minor amounts of encapsulated grains of calcite are still present in the wollastonite crystals - blocky aggregates of the wollastonite are essentially broken down thus, resulting in a higher aspect ratio of between 8:1 and 4:1 - disseminated sulphides (pyrite) occur in trace amounts - approximately 25% of the size fraction as wollastonite
-150	- wollastonite crystals are essentially 98% liberated from any entrained calcite or diopside - aspect ratio is higher at >8:1 - disseminated sulphides are present throughout the size fraction in trace amounts - approximately 25 to 30% of the size fraction as wollastonite

Table 4. Magnetic separation test results for each wollastonite sample

Size range	Products	Wt %	Analysis %				Distribution %			
			Fe_2O_3	Al_2O_3	MgO	LOI	Fe_2O_3	Al_2O_3	MgO	LOI
-420 +150 Green phase	Magnetics	11.0	1.46	0.32	2.21	20.0	47.5	26.3	49.4	7.0
	Non magnetics	89.0	0.20	0.11	0.28	32.6	52.5	73.7	50.6	93.0
	Head (calculated)	100.0	0.34	0.13	0.49	31.2	100.0	100.0	100.0	100.0
-150 Green phase	Magnetics	8.9	4.17	0.92	9.10	7.3	74.3	33.9	90.0	2.8
	Middlings	7.1	0.38	0.24	0.44	19.8	5.5	7.0	3.4	6.0
	Non magnetics	84.0	0.12	0.17	0.07	25.5	20.2	59.1	6.6	91.2
	Head (calculated)	100.0	0.50	0.24	0.90	23.5	100.0	100.0	100.0	100.0
-420 +150 White phase	Magnetics	1.3	1.00	0.86	3.31	17.4	3.1	2.9	6.6	0.8
	Non magnetics	98.7	0.32	0.38	0.62	28.8	96.9	97.1	93.4	99.2
	Head (calculated)	100.0	0.33	0.39	0.65	28.7	100.0	100.0	100.0	100.0
-150 White phase	Magnetics	5.2	1.35	1.00	4.29	5.1	15.8	10.3	34.1	0.9
	Middlings	3.3	0.75	0.65	1.41	28.6	5.6	4.2	7.2	3.3
	Non magnetics	91.5	0.38	0.47	0.42	30.4	78.6	85.5	58.7	95.8
	Head (calculated)	100.0	0.44	0.59	1.01	29.0	100.0	100.0	100.0	100.0

Table 5. Product balances for unground green-phase wollastonite at constant pH using variable sodium oleate concentration: -420 +150 μm

Test No.	Products	Bright %	Wt %	Analysis %			Distribution %	
				Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
1	1st Rgh. float	66.9	2.9	0.13	41.3	96.3	1.8	3.8
	2nd Rgh. float	68.2	1.3	0.13	40.2	94.5	0.9	1.7
	3rd Rgh. float	63.8	3.4	0.13	41.1	95.4	1.8	4.5
	4th Rgh. float	68.3	11.4	0.13	41.1	95.6	6.7	15.1
	5th Rgh. float	65.2	16.4	0.14	39.4	94.4	10.4	20.8
	6th Rgh. float	61.9	18.4	0.21	39.0	92.9	17.6	23.0
	7th Rgh. float	59.0	17.6	0.27	35.8	88.7	21.6	20.2
	8th Rgh. float	55.7	6.0	0.40	32.8	-	10.8	6.3
	Rgh. tails	59.3	22.6	0.28	6.4	-	28.4	4.6
	Head (calculated)	-	100.0	0.22	31.1	74.1	100.0	100.0
2	Final conc.	62.9	68.9	0.20	39.9	94.1	58.5	90.8
	2nd cleaner tails	-	6.0	0.30	15.0	-	7.6	3.0
	1st cleaner tails	-	5.1	0.28	14.0	-	5.9	2.4
	Rgh. tails	59.4	20.0	0.33	5.8	-	28.0	3.8
	Head (calculated)	-	100.0	0.24	30.3	72.0	100.0	100.0
3	Final conc.	64.9	48.5	0.14	40.7	95.9	30.6	67.3
	2nd cleaner tails	-	10.3	0.20	37.6	92.2	9.5	13.2
	1st cleaner tails	-	12.5	0.24	20.0	-	13.5	8.5
	Rgh. tails	58.8	28.7	0.36	11.2	-	46.4	11.0
	Head (calculated)	-	100.0	0.22	29.3	69.8	100.0	100.0

Table 6. Product balances for green-phase wollastonite ground to different sizes with constant pH and sodium oleate collector concentration: -420 +150 μm

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
4	Final conc.	13.5	67.2	65.9	0.19	39.4	94.5	51.2	88.5
	2nd Cleaner tails		-	2.7	0.25	30.6	-	2.9	2.8
	1st Cleaner tails		-	3.8	0.33	20.6	-	5.3	2.7
	Rgh. tails		62.7	27.6	0.36	6.4	-	40.6	6.0
	Head (calculated)		-	100.0	0.24	29.4	71.8	100.0	100.0
5	Final conc.	19.0	71.0	66.6	0.14	38.8	92.3	33.9	91.2
	2nd Cleaner tails		-	2.5	0.47	14.9	-	4.4	1.3
	1st Cleaner tails		-	2.6	0.42	18.0	-	4.0	1.7
	Rgh. tails		64.0	28.3	0.56	5.8	-	57.7	5.8
	Head (calculated)		-	100.0	0.27	28.3	67.4	100.0	100.0
6	Final conc.	28.3	74.0	65.9	0.10	41.3	96.2	26.3	91.4
	2nd Cleaner tails		-	1.1	0.30	20.1	-	1.2	0.7
	1st Cleaner tails		-	6.3	0.51	18.2	-	12.7	3.9
	Rgh. tails		65.0	26.7	0.56	4.4	-	59.8	4.0
	Head (calculated)		-	100.0	0.25	29.8	70.8	100.0	100.0
7	Final conc.	43.5	77.9	62.2	0.08	41.9	97.5	19.6	87.2
	2nd Cleaner tails		-	2.2	0.29	31.3	-	2.4	2.3
	1st Cleaner tails		-	11.1	0.42	24.3	-	18.4	9.0
	Rgh. tails		68.5	24.5	0.62	1.9	-	59.6	1.5
	Head (calculated)		-	100.0	0.26	29.9	71.1	100.0	100.0

Table 7. Product balances for ground green-phase wollastonite indicating the influence of variable size and sodium oleate collector concentration at constant pH: -420 +150 μm

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
5	Final conc.	19.0	71.0	66.6	0.14	38.8	92.3	33.9	91.2
	2nd Cleaner tails		-	2.5	0.47	14.9	-	4.4	1.3
	1st Cleaner tails		-	2.6	0.42	18.0	-	4.0	1.7
	Rgh. tails		64.0	28.3	0.56	5.8	-	57.7	5.8
	Head (calculated)		-	100.0	0.27	28.3	67.4	100.0	100.0
8	Final conc.	19.0	73.3	69.1	0.16	40.2	93.6	46.3	91.9
	2nd Cleaner tails		-	2.8	0.27	23.9	-	3.3	2.2
	1st Cleaner tails		-	6.9	0.40	15.6	-	11.7	3.6
	Rgh. tails		67.0	21.2	0.44	3.3	-	38.7	2.3
	Head (calculated)		-	100.0	0.24	30.2	72.0	100.0	100.0
7	Final conc.	43.5	77.9	62.2	0.08	41.9	97.5	19.6	87.2
	2nd Cleaner tails		-	2.2	0.29	31.3	-	2.4	2.3
	1st Cleaner tails		-	11.1	0.42	24.3	-	18.4	9.0
	Rgh. tails		68.5	24.5	0.62	1.9	-	59.6	1.5
	Head (calculated)		-	100.0	0.26	29.9	71.1	100.0	100.0
9	Final conc.	43.5	77.3	70.3	0.13	40.8	95.0	34.6	95.3
	2nd Cleaner tails		-	3.3	0.54	14.2	-	6.9	1.6
	1st Cleaner tails		-	4.7	0.50	9.8	-	9.1	1.5
	Rgh. tails		69.2	21.7	0.60	2.3	-	49.4	1.6
	Head (calculated)		-	100.0	0.26	30.1	71.6	100.0	100.0

Table 8. Product balances for ground green-phase wollastonite at variable Arquad T 50 concentration while maintaining constant pH and grind size: -420 +150 μm

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
10	Final conc.	50	63.4	12.7	0.46	4.4	-	19.9	1.9
	1st Cleaner tails		-	5.7	0.38	16.1	-	7.5	3.0
	Rgh. tails		69.2	81.6	0.26	35.3	84.0	72.6	95.1
	Head (calculated)		-	100.0	0.29	30.3	72.1	100.0	100.0
11	Final conc.	75	62.6	17.7	0.46	8.1	-	33.9	4.7
	1st Cleaner tails		-	12.2	0.32	20.2	-	16.3	8.2
	Rgh. tails		68.7	70.1	0.17	37.5	89.9	49.8	87.1
	Head (calculated)		-	100.0	0.24	30.1	71.7	100.0	100.0
12	Final conc.	100	61.8	19.8	0.44	8.3	-	37.2	5.6
	1st Cleaner tails		-	14.0	0.38	18.6	-	22.8	8.6
	Rgh. tails		69.0	66.2	0.14	39.0	94.3	39.9	85.8
	Head (calculated)		-	100.0	0.23	30.0	71.5	100.0	100.0

Table 9. Product balances for ground green-phase wollastonite indicating the effect of variable grind size at constant Arquad T 50 concentration and pH: -420 +150 μm

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
11	Final conc.	13.5	62.6	17.7	0.46	8.1	-	33.9	4.7
	1st Cleaner tails		-	12.2	0.32	20.2	-	16.3	8.2
	Rgh. tails		68.7	70.1	0.17	37.5	89.9	49.8	87.1
	Head (calculated)		-	100.0	0.24	30.1	71.7	100.0	100.0
13	Final conc.	19.0	75.2	24.1	0.52	7.2	-	47.0	5.8
	1st Cleaner tails		-	3.3	0.30	23.9	-	3.8	2.7
	Rgh. tails		83.8	72.6	0.18	37.6	89.6	49.2	91.5
	Head (calculated)		-	100.0	0.27	29.8	71.0	100.0	100.0
14	Final conc.	28.3	76.3	23.7	0.55	6.5	-	49.0	5.2
	1st Cleaner tails		-	6.8	0.36	19.7	-	9.1	4.5
	Rgh. tails		84.3	69.5	0.16	38.8	92.3	41.9	90.3
	Head (calculated)		-	100.0	0.27	29.8	71.0	100.0	100.0
15	Final conc.	43.5	72.4	20.6	0.60	4.8	-	47.3	3.3
	1st Cleaner tails		-	5.5	0.36	22.1	-	7.6	4.0
	Rgh. tails		83.4	73.9	0.16	37.9	90.3	45.1	92.7
	Head (calculated)		-	100.0	0.26	30.2	72.0	100.0	100.0

Table 10. Product balances for unground (-150 μm) green-phase wollastonite indicating the influence of variable sodium oleate concentration at constant pH

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
16	Final conc.	310	73.0	59.7	0.11	41.2	96.4	50.0	93.9
	2nd Cleaner tails		-	1.8	0.30	13.9	-	3.8	1.0
	1st Cleaner tails		-	5.1	0.22	11.0	-	8.3	2.1
	Rgh. tails		72.2	33.4	0.15	2.3	-	37.9	3.0
	Head (calculated)		-	100.0	0.13	26.2	62.3	100.0	100.0
17	Final conc.	365	73.3	60.7	0.10	41.0	95.9	50.0	94.7
	2nd Cleaner tails		-	2.3	0.21	19.5	-	4.1	1.7
	1st Cleaner tails		-	5.8	0.21	6.9	-	9.8	1.5
	Rgh. tails		73.0	31.2	0.14	1.8	-	36.1	2.1
	Head (calculated)		-	100.0	0.12	26.3	62.5	100.0	100.0
18	Final conc.	420	72.4	61.3	0.11	40.3	95.1	52.8	95.0
	2nd Cleaner tails		-	2.0	0.23	12.9	-	3.9	1.0
	1st Cleaner tails		-	6.7	0.19	7.6	-	10.2	2.0
	Rgh. tails		72.7	30.0	0.14	1.8	-	33.1	2.0
	Head (calculated)		-	100.0	0.13	26.0	61.9	100.0	100.0

Table 11. Product balances for unground (-150 μm) green-phase wollastonite indicating the influence of variable pH at constant sodium oleate concentration

Test No.	Products	pH	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
16	Final conc.	7.0	73.0	59.7	0.11	41.2	96.4	50.0	93.9
	2nd Cleaner tails		-	1.8	0.30	13.9	-	3.8	1.0
	1st Cleaner tails		-	5.1	0.22	11.0	-	8.3	2.1
	Rgh. tails		72.2	33.4	0.15	2.3	-	37.9	3.0
	Head (calculated)		-	100.0	0.13	26.2	62.3	100.0	100.0
19	Final conc.	8.0	74.3	61.2	0.11	40.0	95.3	54.0	92.3
	2nd Cleaner tails		-	4.2	0.19	19.5	-	6.5	3.1
	1st Cleaner tails		-	8.4	0.18	7.3	-	12.1	2.3
	Rgh. tails		72.9	26.2	0.13	2.3	-	27.4	2.3
	Head (calculated)		-	100.0	0.12	26.5	63.1	100.0	100.0
20	Final conc.	9.0	74.0	60.3	0.10	39.5	95.1	44.8	92.0
	2nd Cleaner tails		-	5.6	0.24	14.1	-	9.7	3.1
	1st Cleaner tails		-	10.6	0.15	8.5	-	11.9	3.5
	Rgh. tails		73.2	23.5	0.19	1.6	-	33.6	1.4
	Head (calculated)		-	100.0	0.13	25.9	61.6	100.0	100.0

Table 12. Product balance for ground (-150 μm) green-phase wollastonite indicating the effect of variable grind size at constant sodium oleate concentration and pH

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
16	Final conc.	64.2	73.0	59.7	0.11	41.2	96.4	50.0	93.9
	2nd Cleaner tails		-	1.8	0.30	13.9	-	3.8	1.0
	1st Cleaner tails		-	5.1	0.22	11.0	-	8.3	2.1
	Rgh. tails		72.2	33.4	0.15	2.3	-	37.9	3.0
	Head (calculated)		-	100.0	0.13	26.2	62.3	100.0	100.0
21	Final conc.	75.0	84.3	46.4	0.08	42.2	98.8	18.2	76.5
	2nd Cleaner tails		-	4.8	0.14	52.5	-	3.5	9.8
	1st Cleaner tails		-	9.3	0.23	25.1	-	10.3	9.1
	Rgh. tails		72.5	39.5	0.35	2.9	-	68.0	4.6
	Head (calculated)		-	100.0	0.20	25.6	60.9	100.0	100.0
22	Final conc.	83.8	86.2	32.9	0.06	42.3	99.0	9.4	55.2
	2nd Cleaner tails		-	9.6	0.09	50.8	-	4.2	19.4
	1st Cleaner tails		-	13.8	0.25	28.3	-	16.4	15.5
	Rgh. tails		73.0	43.7	0.34	5.7	-	70.0	9.9
	Head (calculated)		-	100.0	0.21	25.2	59.9	100.0	100.0

Table 13. Product balance for unground (-150 μm) green-phase wollastonite at constant pH and variable Arquad T 50 concentration

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
23	Final conc.	75	70.0	27.9	0.26	2.9	-	53.2	3.3
	1st Cleaner tails		-	7.0	0.17	18.3	-	8.8	5.1
	Rgh. tails		73.8	65.1	0.08	35.5	84.4	38.0	91.6
	Head (calculated)		-	100.0	0.14	25.2	60.0	100.0	100.0
24	Final conc.	100	70.6	28.3	0.22	3.3	-	47.6	3.6
	1st Cleaner tails		-	10.3	0.18	18.9	-	14.7	7.5
	Rgh. tails		73.5	61.4	0.08	37.2	88.6	37.7	88.9
	Head (calculated)		-	100.0	0.13	25.7	61.2	100.0	100.0
25	Final conc.	130	70.0	38.3	0.27	5.5	-	69.1	8.3
	1st Cleaner tails		-	8.8	0.16	26.3	-	9.4	9.1
	Rgh. tails		73.3	52.9	0.06	39.8	96.4	21.5	82.6
	Head (calculated)		-	100.0	0.15	25.5	60.6	100.0	100.0

Table 14. Product balance for ground (-150 μm) green-phase wollastonite indicating the effect of variable grind size at constant Arquad T 50 concentration and pH

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
24	Final conc.	64.2	70.6	28.3	0.22	3.3	-	47.6	3.6
	1st Cleaner tails		-	10.3	0.18	18.9	-	14.7	7.5
	Rgh. tails		73.5	61.4	0.08	37.2	88.6	37.7	88.9
	Head (calculated)		-	100.0	0.13	25.7	61.2	100.0	100.0
26	Final conc.	75.0	74.3	33.0	0.33	3.8	-	54.5	5.3
	1st Cleaner tails		-	18.4	0.28	21.4	-	26.0	16.6
	Rgh. tails		79.3	48.6	0.08	38.2	91.0	19.5	78.1
	Head (calculated)		-	100.0	0.20	23.8	56.6	100.0	100.0
27	Final conc.	83.8	75.2	26.7	0.23	4.8	-	36.5	5.0
	1st Cleaner tails		-	12.9	0.26	18.4	-	20.4	9.2
	Rgh. tails		74.3	60.4	0.12	36.7	87.4	43.1	85.8
	Head (calculated)		-	100.0	0.17	25.8	61.5	100.0	100.0

Table 15. Product balance for ground white-phase wollastonite at variable sodium oleate concentration while maintaining constant pH and grind size: -420 +150 μm

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
28	Final conc.	205	83.5	64.6	0.26	39.7	93.7	47.2	90.9
	1st Cleaner tails		-	5.4	0.32	16.0	-	4.8	3.1
	Rgh. tails		72.5	30.0	0.57	5.7	-	48.0	6.0
	Head (calculated)		-	100.0	0.36	28.2	67.1	100.0	100.0
29	Final conc.	260	79.8	59.5	0.29	39.4	93.8	51.6	86.2
	1st Cleaner tails		-	8.6	0.32	20.7	-	8.4	6.6
	Rgh. tails		75.8	31.9	0.42	6.1	-	40.0	7.2
	Head (calculated)		-	100.0	0.34	27.2	64.7	100.0	100.0
30	Final conc.	305	79.0	29.7	0.14	40.8	97.1	12.9	54.6
	1st Cleaner tails		-	3.1	0.24	22.6	-	2.2	3.2
	Rgh. tails		70.1	67.2	0.41	14.0	-	84.9	42.2
	Head (calculated)		-	100.0	0.32	22.2	52.8	100.0	100.0
31	Final conc.	360	82.5	48.1	0.25	40.4	96.2	32.4	76.9
	1st Cleaner tails		-	7.0	0.35	22.1	-	6.8	6.1
	Rgh. tails		75.0	44.9	0.50	9.6	-	60.8	17.0
	Head (calculated)		-	100.0	0.37	25.3	60.2	100.0	100.0

Table 16. Product balance for ground white-phase wollastonite at constant pH and grind size with variable Arquad T 50 concentration: -420 +150 μm

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
32	Final conc.	50	63.6	11.5	1.35	2.7	-	48.0	1.0
	1st Cleaner tails		-	2.9	0.49	14.2	-	4.3	1.5
	Rgh. tails		83.2	85.6	0.18	32.2	76.6	47.7	97.5
	Head (calculated)		-	100.0	0.33	28.3	67.3	100.0	100.0
33	Final conc.	75	70.7	23.0	0.84	5.8	-	63.1	4.8
	1st Cleaner tails		-	9.8	0.40	14.3	-	12.7	4.9
	Rgh. tails		83.6	67.2	0.11	37.9	91.3	24.2	90.3
	Head (calculated)		-	100.0	0.31	28.2	67.1	100.0	100.0
34	Final conc.	100	72.5	23.4	0.79	6.2	-	47.4	5.2
	1st Cleaner tails		-	8.8	0.47	13.8	-	28.2	4.3
	Rgh. tails		83.5	67.8	0.14	37.4	89.8	24.4	90.5
	Head (calculated)		-	100.0	0.39	28.0	66.7	100.0	100.0

Table 17. Product balance for ground white-phase wollastonite indicating the effect of variable grind size at constant sodium oleate concentration and pH: -420 +150 μm

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
28	Final conc.	23.4	83.5	64.6	0.26	39.7	93.7	47.2	90.9
	1st Cleaner tails		-	5.4	0.32	16.0	-	4.8	3.1
	Rgh. tails		72.5	30.0	0.57	5.7	-	48.0	6.0
	Head (calculated)		-	100.0	0.36	28.2	67.2	100.0	100.0
35	Final conc.	29.1	87.2	60.7	0.13	40.6	96.2	24.1	86.4
	1st Cleaner tails		-	6.6	0.35	23.6	-	7.0	5.5
	Rgh. tails		69.3	32.7	0.69	7.1	-	68.9	8.1
	Head (calculated)		-	100.0	0.33	28.5	67.9	100.0	100.0
36	Final conc.	38.3	85.2	49.6	0.08	41.0	97.2	12.2	71.2
	1st Cleaner tails		-	8.3	0.22	33.2	-	5.5	9.7
	Rgh. tails		71.9	42.1	0.64	13.0	-	82.3	19.1
	Head (calculated)		-	100.0	0.33	28.6	68.0	100.0	100.0

Table 18. Product balance for ground white-phase wollastonite indicating the effect of variable pH and grind size at constant Arquad T 50 concentration: -420 +150 μm

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
33	Final conc.	23.4	70.7	23.0	0.84	5.8	-	63.5	4.8
	1st Cleaner tails		-	9.8	0.40	14.3	-	12.8	4.9
	Rgh. tails		83.6	67.2	0.11	37.9	91.3	23.7	90.3
	Head (calculated)		-	100.0	0.31	28.2	67.1	100.0	100.0
37	Final conc.	29.1	70.0	23.1	0.91	4.7	-	64.0	3.8
	1st Cleaner tails		-	8.1	0.43	16.2	-	10.7	4.5
	Rgh. tails		86.0	68.8	0.12	38.4	91.4	25.3	91.7
	Head (calculated)		-	100.0	0.33	28.9	68.7	100.0	100.0
38	Final conc.	38.3	73.0	25.6	0.84	5.1	-	67.8	4.7
	1st Cleaner tails		-	7.4	0.47	17.7	-	11.1	4.8
	Rgh. tails		86.2	67.0	0.10	37.2	88.5	21.1	90.5
	Head (calculated)		-	100.0	0.32	27.5	65.5	100.0	100.0

Table 19. Product balance for unground (-150 μm) white-phase wollastonite indicating the influence of variable sodium oleate concentration at constant pH

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
39	Final conc.	200	80.3	64.5	0.21	40.3	95.9	34.6	86.1
	1st Cleaner tails		-	4.4	0.58	21.3	-	6.6	3.1
	Rgh. tails		70.7	31.1	0.74	10.5	-	58.8	10.8
	Head (calculated)		-	100.0	0.39	30.2	71.9	100.0	100.0
40	Final conc.	255	79.8	68.2	0.27	40.6	95.8	46.2	90.5
	1st Cleaner tails		-	5.9	0.78	21.5	-	11.6	4.2
	Rgh. tails		71.1	25.9	0.65	6.3	-	42.2	5.3
	Head (calculated)		-	100.0	0.40	30.6	72.8	100.0	100.0
41	Final conc.	305	76.9	73.2	0.39	40.1	95.5	67.9	95.8
	1st Cleaner tails		-	3.6	0.46	11.5	-	4.0	1.3
	Rgh. tails		71.3	23.2	0.51	3.8	-	28.1	2.9
	Head (calculated)		-	100.0	0.42	30.7	72.1	100.0	100.0

Table 20. Product balance for unground (-150 μm) white-phase wollastonite at constant pH and variable Arquad T 50 concentration

Test No.	Products	Collector concn	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
42	Final conc.	50	60.7	12.1	2.07	2.1	-	66.5	0.8
	1st Cleaner tails		-	7.5	0.40	18.1	-	8.0	4.5
	Rgh. tails		81.0	80.4	0.12	35.7	89.1	25.5	94.7
	Head (calculated)		-	100.0	0.38	30.3	72.1	100.0	100.0
43	Final conc.	75	68.9	29.2	1.07	9.6	-	78.0	9.1
	1st Cleaner tails		-	10.4	0.33	31.6	-	8.5	10.7
	Rgh. tails		84.2	60.4	0.09	40.9	97.2	13.5	80.2
	Head (calculated)		-	100.0	0.40	30.6	73.2	100.0	100.0
44	Final conc.	100	71.4	37.3	0.83	15.8	-	69.8	19.8
	1st Cleaner tails		-	11.4	0.73	27.5	-	18.7	10.5
	Rgh. tails		82.4	51.3	0.10	40.5	96.3	11.5	69.7
	Head (calculated)		-	100.0	0.44	29.8	70.9	100.0	100.0

Table 21. Product balance for ground (-150 μm) white-phase wollastonite indicating the effect of variable grind size at constant sodium oleate concentration and pH

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
41	Final conc.	64.9	76.9	73.2	0.39	40.1	95.5	67.9	95.8
	1st Cleaner tails		-	3.6	0.46	11.5	-	4.0	1.3
	Rgh. tails		71.3	23.2	0.51	3.8	-	28.1	2.9
	Head (calculated)		-	100.0	0.42	30.7	72.1	100.0	100.0
45	Final conc.	75.9	82.6	64.5	0.15	41.3	98.3	25.9	86.7
	1st Cleaner tails		-	4.0	0.50	21.1	-	5.3	2.7
	Rgh. tails		70.3	31.5	0.82	10.3	-	68.8	10.6
	Head (calculated)		-	100.0	0.38	30.7	73.1	100.0	100.0
46	Final conc.	84.8	82.2	61.3	0.10	41.5	98.8	16.4	83.4
	1st Cleaner tails		-	3.7	0.55	18.6	-	5.4	2.3
	Rgh. tails		69.9	35.0	0.83	12.5	-	78.2	14.3
	Head (calculated)		-	100.0	0.37	30.5	72.6	100.0	100.0
47	Final conc.	90.1	80.7	47.7	0.09	42.0	99.2	9.9	64.8
	1st Cleaner tails		-	6.2	0.36	30.2	-	5.2	6.1
	Rgh. tails		70.1	46.1	0.78	19.5	-	84.9	29.1
	Head (calculated)		-	100.0	0.42	30.9	73.5	100.0	100.0

Table 22. Product balance for ground (-150 μm) white-phase wollastonite indicating the effect of variable grind size at constant Arquad T 50 concentration and pH

Test No.	Products	Size % -75 μm	Bright %	Wt %	Analysis %			Distribution %	
					Fe_2O_3	LOI	$CaCO_3$	Fe_2O_3	LOI
43	Final conc.	64.9	68.9	29.2	1.07	9.6	-	78.0	9.1
	1st Cleaner tails		-	10.4	0.33	31.6	-	8.5	10.7
	Rgh. tails		84.2	60.4	0.09	40.9	97.2	13.5	80.2
	Head (calculated)		-	100.0	0.40	30.8	73.2	100.0	100.0
48	Final conc.	75.9	70.9	24.6	0.84	6.6	-	61.6	5.4
	1st Cleaner tails		-	9.7	0.38	29.1	-	11.0	9.4
	Rgh. tails		80.7	65.7	0.14	39.1	93.1	27.4	85.2
	Head (calculated)		-	100.0	0.34	30.1	75.6	100.0	100.0
49	Final conc.	84.8	69.0	22.5	0.82	5.7	-	44.5	4.1
	1st Cleaner tails		-	9.7	0.42	28.4	-	9.8	8.9
	Rgh. tails		81.3	67.8	0.28	39.8	94.7	45.7	87.0
	Head (calculated)		-	100.0	0.42	31.0	73.8	100.0	100.0
50	Final conc.	90.1	69.0	19.6	0.84	5.6	-	47.8	3.6
	1st Cleaner tails		-	8.8	0.42	27.7	-	10.7	7.9
	Rgh. tails		81.0	71.6	0.20	38.0	90.4	41.5	88.5
	Head (calculated)		-	100.0	0.35	30.8	73.2	100.0	100.0

Table 23. Flotation parameter and reagent concentration data for -420 +150 μm green-phase wollastonite

Test No.	Flotation stage	Float time min	Grind time min	pH	Collector		Frother
					Sodium oleate g/t	Arquad T 50 g/t	M.I.B.C. g/t
1	Rougher	28	-	7.0	410	-	200
2	Rougher	4	-	7.0	405	-	55
	Cleaner	8	-	7.0	75	-	55
3	Rougher	3	-	7.0	305	-	20
	Cleaner	6	-	7.0	100	-	40
4	Rougher	3	3	7.0	310	-	40
	Cleaner	6	-	7.0	105	-	75
5	Rougher	3	5	7.0	310	-	20
	Cleaner	6	-	7.0	105	-	40
6	Rougher	4	10	7.0	310	-	20
	Cleaner	6	-	7.0	105	-	40
7	Rougher	4	15	7.0	310	-	40
	Cleaner	8	-	7.0	105	-	40
8	Rougher	3	5	7.0	420	-	40
	Cleaner	6	-	7.0	155	-	40
9	Rougher	3	15	7.0	420	-	40
	Cleaner	5	-	7.0	155	-	40
10	Rougher	2	3	9.0	-	50	20
	Cleaner	1	-	8.9	-	15	20
11	Rougher	2	3	9.1	-	75	20
	Cleaner	2	-	9.1	-	25	-
12	Rougher	2	3	9.2	-	100	20
	Cleaner	2	-	9.0	-	35	20
13	Rougher	2	5	9.4	-	75	20
	Cleaner	2	-	9.2	-	25	-
14	Rougher	3	10	9.4	-	75	20
	Cleaner	2	-	9.1	-	25	-
15	Rougher	3	15	9.5	-	75	20
	Cleaner	2	-	9.1	-	25	-

Table 24. Flotation parameter and reagent concentration data for -150 μm green-phase wollastonite

Test No.	Flotation stage	Float time min	Grind time min	pH	Collector		Frother
					Sodium oleate g/t	Arquad T 50 g/t	M.I.B.C. g/t
16	Rougher	1	-	7.0	310	-	75
	Cleaner	3	-	7.1	105	-	75
17	Rougher	2	-	7.0	365	-	75
	Cleaner	4	-	7.0	105	-	75
18	Rougher	2	-	7.0	420	-	75
	Cleaner	4	-	7.0	155	-	75
19	Rougher	2	-	7.8	310	-	75
	Cleaner	4	-	8.0	105	-	75
20	Rougher	3	-	9.0	310	-	75
	Cleaner	5	-	9.0	105	-	75
21	Rougher	4	5	7.0	310	-	20
	Cleaner	6	-	7.0	105	-	-
22	Rougher	4	10	7.0	310	-	20
	Cleaner	6	-	7.0	105	-	-
23	Rougher	2	-	8.8	-	75	40
	Cleaner	1	-	8.8	-	40	40
24	Rougher	2	-	9.0	-	100	40
	Cleaner	1	-	9.0	-	35	40
25	Rougher	2	-	8.9	-	130	40
	Cleaner	2	-	8.9	-	50	40
26	Rougher	6	5	9.2	-	100	40
	Cleaner	2	-	9.1	-	35	-
27	Rougher	3	10	9.4	-	100	40
	Cleaner	2	-	9.2	-	35	-

Table 25. Flotation parameter and reagent concentration data for -420 +150 μm white-phase wollastonite

Test No.	Flotation stage	Float time min	Grind time min	pH	Collector		Frother
					Sodium oleate g/t	Arquad T 50 g/t	M.I.B.C. g/t
28	Rougher	3	5	7.0	205	-	20
	Cleaner	2	-	7.0	65	-	-
29	Rougher	2	5	7.0	260	-	20
	Cleaner	1	-	7.0	85	-	20
30	Rougher	2	5	7.0	305	-	-
	Cleaner	1	-	7.0	100	-	-
31	Rougher	2	5	7.0	360	-	-
	Cleaner	1	-	7.0	120	-	-
32	Rougher	2	5	7.0	-	50	20
	Cleaner	1	-	7.0	-	15	-
33	Rougher	2	5	7.0	-	75	-
	Cleaner	2	-	7.0	-	25	-
34	Rougher	2	5	7.0	-	100	20
	Cleaner	1	-	7.0	-	40	-
35	Rougher	3	10	7.0	205	-	20
	Cleaner	2	-	7.0	65	-	-
36	Rougher	3	15	7.0	205	-	20
	Cleaner	3	-	7.0	65	-	-
37	Rougher	2	10	9.3	-	75	-
	Cleaner	2	-	9.1	-	25	-
38	Rougher	2	15	9.3	-	75	-
	Cleaner	2	-	9.0	-	25	-

Table 26. Flotation parameter and reagent concentration data for -150 μm white-phase wollastonite

Test No.	Flotation stage	Cond. time min	Float time min	Grind time min	pH	Collector		Frother
						Sodium oleate g/t	Arquad T 50 g/t	M.I.B.C. g/t
39	Rougher	4	4	-	7.0	200	-	-
	Cleaner	4	3	-	7.0	65	-	-
40	Rougher	4	3	-	7.0	255	-	-
	Cleaner	4	2	-	7.0	80	-	-
41	Rougher	4	3	-	7.0	305	-	-
	Cleaner	4	2	-	7.0	100	-	-
42	Rougher	4	3	-	7.0	-	50	20
	Cleaner	4	1	-	7.0	-	15	-
43	Rougher	4	2	-	7.0	-	75	20
	Cleaner	4	2	-	6.9	-	25	-
44	Rougher	4	2	-	7.0	-	100	20
	Cleaner	4	2	-	7.0	-	40	-
45	Rougher	-	4	5	7.0	305	-	-
	Cleaner	-	3	-	7.0	100	-	-
46	Rougher	-	4	10	7.0	305	-	-
	Cleaner	-	3	-	7.0	100	-	-
47	Rougher	-	4	15	7.0	305	-	-
	Cleaner	-	3	-	7.0	100	-	-
48	Rougher	-	3	5	9.1	-	75	20
	Cleaner	-	2	-	9.0	-	25	-
49	Rougher	-	3	10	9.0	-	75	20
	Cleaner	-	2	-	8.9	-	25	-
50	Rougher	-	3	15	9.1	-	75	20
	Cleaner	-	2	-	8.9	-	25	-